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GUIDELINES FOR DESIGN AND EVALUATION OF PUBLIC AND NON-MOTORISED TRANSPORT SYSTEMS FOR SUSTAINABILITY

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GUIDELINES FOR DESIGN AND EVALUATION OF PUBLIC AND NON-MOTORISED TRANSPORT SYSTEMS FOR SUSTAINABILITY

1. INTRODUCTION

India's population is steadily rising and as a result it is expected that India would become most populous country by 2050. Due to increase in population, there is many times increase in vehicles specially in urban areas. Deficiencies and lack of appropriate supply of public transport related infrastructure is also leading to more and more increase of personal vehicles which is further creating problems of congested urban roads, jams, accidents etc. So a need was felt to prepare guidelines on sustainable transportation system which can help in reducing the negative effects of transportation on the society as a whole. The task of preparation of this document was taken up by the Transport Planning and Traffic Engineering Committee (H-1) of the Indian Roads Congress. A subgroup consisting of Dr. E. Madhu (Chairman), Dr. Rajat Rastogi, Dr. Sewa Ram and Shri Shaheem S. was constituted to prepare the draft. The draft prepared by the subgroup was deliberated in a series of meetings and was finalized in its meeting held on 29.05.2020.

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The revised draft document was placed before the Highways Specifications and Standards Committee (HSS) in its meeting held on 12.09.2020 and continued on 19.09.2020 & 03.10.2020. The HSS Committee decided that the Convenor, H-1 Committee will modify the document based on written and verbal comments offered during the meeting and submit the final document to IRC for placing before the meetings of Executive Committee (EC) and Council. The modified document considering the suggestions of the HSS committee was deliberated and approved by the EC in its meeting held on 18.02.2021. The 221st Mid-Term Council in its meeting held on 20th – 21st February, 2021 considered and approved the draft "Guidelines for Design and Evaluation of Public and Non-Motorised Transport Systems for Sustainability" for printing.

1.1 Concept of Sustainability

Sustainable development is a holistic practice that includes efforts to mitigate negative effects on every part of the road infrastructure and transportation system which are generally ignored in traditional transportation system planning. Sustainability focuses on meeting the needs of the present without compromising the ability of future generations to meet their needs. The concept of sustainability is composed of three pillars: economic, environmental, and social. Sustainability encourages policy makers or urban development authorities to frame decisions in terms of environmental, social, and human impact for the long-term, rather than on short-term gains. It influences them to consider more factors than simply the immediate profit or loss involved. Sustainable transportation system should consider the interconnected issues under social, economy and environment areas as shown in **Fig. 1.1**. As can be seen from the **Fig. 1.1**, social and economical issues lead to equitable; social and environment leads to bearable; and economic and environment leads to viable solutions. If a system considers parameters related to all the three pillars i.e. social, economic and environment simultaneously, then it would be called a sustainable system.

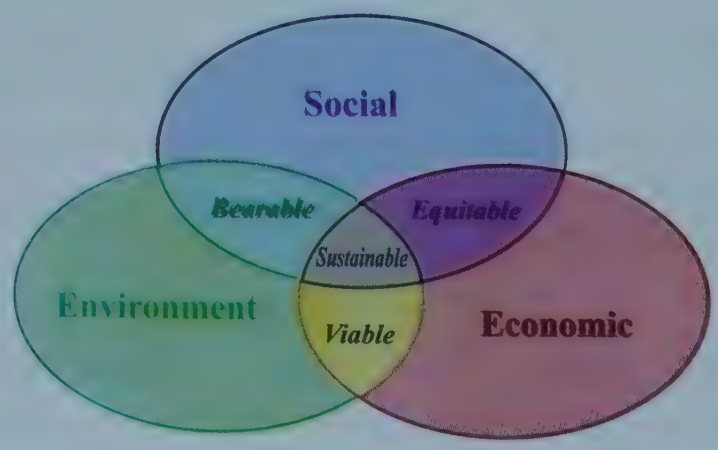


Fig. 1.1 Sustainable System and its Interconnections

1.2 Need of Sustainability

The need for sustainable transport system is evident since global warming possesses significant challenges for cities. The transport sector alone accounts for 24% of CO_2 emissions worldwide. The energy consumption is about 75 to 80% by road transport and India's share is about 10%

from all transport modes. The safety of road user is also a major concern towards achievement of sustainability. Traffic congestion during peak hours in four major cities (Delhi, Mumbai, Kolkata and Bangalore) costs around 1.5 lakh crores annually. On Indian roads, about 1.5 lakhs deaths occur in fatal crashes in a year which is 3% of GDP.

Govt. of India has launched Smart Cities Mission recently and proposes more than 100 cities to be developed as Smart Cities. The main objective of this mission is to promote cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment and application of 'Smart' Solutions. The core infrastructure elements in a Smart City are: efficient urban mobility, public transport and sustainable environment. However, there are no proper guidelines existing currently which can be considered by the urban development authorities to implement or evaluate different types of sustainable transportation systems.

Sustainability performance measures or indices are required to link actions of stakeholders (urban development authorities or transport corporations or public transport operators) to their overall mission and goals. Sustainability performance measures can help them to monitor environmental, economic, and social performance. Sustainability performance measures may be used to help prioritize and influence funding decisions (in balance with other measures). Rating or Index systems attempt to quantify performance of transportation decisions or projects. These are intended for use in benchmarking, in identifying areas of success, and in identifying areas of opportunity for improvement. The New York State DOT (NYSDOT) has developed a program called GreenLITES (Leadership in Transportation and Environmental Sustainability), a self-certification program for New York State that awards transportation projects based on the extent to which they incorporate sustainable design choices. GreenLITES is an internal management program for NYSDOT to measure performance, recognize good practices, and identify improvements where needed. The program allows transportation project designs with environmentally sustainable features to be eligible for green certification. Projects are scored according to their impact and contribution to advancing "the state of practice" in furthering sustainability. Other rating systems namely Greenroads by the U.S. Green Building Council (USGBC) is a prototype rating system specifically for the sustainable design and construction of roadways. The benefits include the ability to link sustainability factors with decision-making, and promote more sustainable design and construction.

Ministry of Urban Development (MoUD), Government of India has created a Service Level Benchmark procedure which evaluates the system against well set targets or best practices. The aim is to promote sustainable transportation in the light of National Urban Transport Policy (NUTP) guidelines and create a competitive environment between operating or controlling agencies across and within cities. In this process some good practices being adopted by the World Bank, European Commission Directorate General for Energy and Transportation, China Urban Sustainable Transport Research Center and Thessaloniki, Greece are highlighted. In general, the factors considered relate to availability, efficiency, accessibility, quality, coverage, affordability, safety, environment, demand management and financial sustainability of transport system. A combination of these factors may be used to evaluate the sustainability of the systems like Public Transport (PT), pedestrians and their facilities, Non-Motorised Transport (NMT) facilities, parking facilities and Intermediate Public Transport (IPT) facilities. The outcome can

be in the form of reduced level of pollution and improvement in safety. The intervention of land-use transport integration and intelligent technologies should be explored in the whole process. Though good number of factors have been considered in arriving at the Level-of-Service (LOS) values to examine the current status of transport system, but still there are factors the inclusion of whom will bring in more value to the evaluation approach. The factors being considered are listed in **Table 1.1**.

In view of the above discussion, there is an immediate need of a guideline or toolkit that can help urban development authorities or transport corporations or public transport operators to design, implement and evaluate sustainable transportation systems namely public transportation and Non-Motorised Transport (NMT) in urban areas to promote sustainability as a primary goal.

1.3 Scope of the Document

Based on the need identified in the previous section, the scope of the document is mainly considered to propose guidelines to enhance quality level of existing transport systems in terms of its quality to achieve sustainability. In this document, the focus is given on sustainable modes namely public transport system and Non-Motorised Transport (NMT) system. The document helps in identifying various parameters of public transport and NMT systems to be considered to achieve sustainability along with steps to be followed. This also includes evaluation methodology by proposing the sustainability index as a whole which will help in assessing the status as well as changes occurred due to policy interventions in public transport and NMT systems. Based on this sustainability index, the policy makers or urban development authorities can easily assess the impact of various policy interventions that are implemented.

Table 1.1 Factors considered in Service Level Benchmarking Approach used by MoUD

System	Factors for Evaluation of Level of Service
PT	Presence of organised PT Supply Coverage Wait time Comfort level Fleet utilisation
Pedestrian Facility	Signalised Intersection delay Street lighting City coverage
NMT Facilities	Network covered Encroachment by vehicles Parking facility near interchange
Use of ITS	Traffic surveillance Passenger information system GPS/GPRS Signal synchronization Integrated ticketing system

Travel Speed	Average travel speed of personal vehicle Average travel speed of PT
Parking	On-street paid public parking Ratio of maximum and minimum parking fee
Road Safety	Fatality rate per lakh population Fatality rate for pedestrian and NMT, %
Pollution Levels	SO_2 Oxides of Nitrogen SPM RSPM
Integrated Land-use Transport System	Population density Mixed land-use per major network Development intensity – city wide and along transit corridor Pattern and completeness of network % area under roads % network with exclusive ROW for transit
Financial Sustainability	% non-fare revenue Staff/bus ratio Operating ratio

1.4 Framework to develop Sustainable Transportation

The current trend of infrastructural development in India has led to increased number of private vehicles and reduced trips of public transport, indicating that priority settings for sustainable modes and road infrastructure have not been considered effectively. The need to plan for sustainable transport is evident since global warming and air quality possesses significant challenges for cities. Considering this, a research project titled "Development and Application of Technologies for Sustainable Transportation" was carried out at CSIR-CRRI under 12th Five Year Plan (CSIR-CRRI, 2017). As an outcome, the present guidelines to design and implement sustainable transportation systems and the methodology to evaluate sustainable transportation has been developed with a main focus on public transport and NMT systems. This would mainly include: quality enhancement of public transport system, feeder transport system and parking facilities at public transport terminals, advanced public transport information systems using Intelligent Transport System (ITS) technologies, policy level sustainable strategies to restrict/ control usage of private vehicles, integration of sustainable mass transportation system and evaluation of sustainable transportation system (environment, social and economy).

The broad framework that should be adopted to develop Sustainable Transportation System for any urban area is given in the **Fig. 1.2**. The existing public transportation systems can be converted into sustainable public transportation system by considering the aspects starting from quality enhancement of public transport system, feeder transport system and parking facilities at public transport terminals, advanced public transport information systems using ITS technologies, policy level sustainable strategies to restrict/control usage of private vehicles and integration of sustainable mass transportation system.

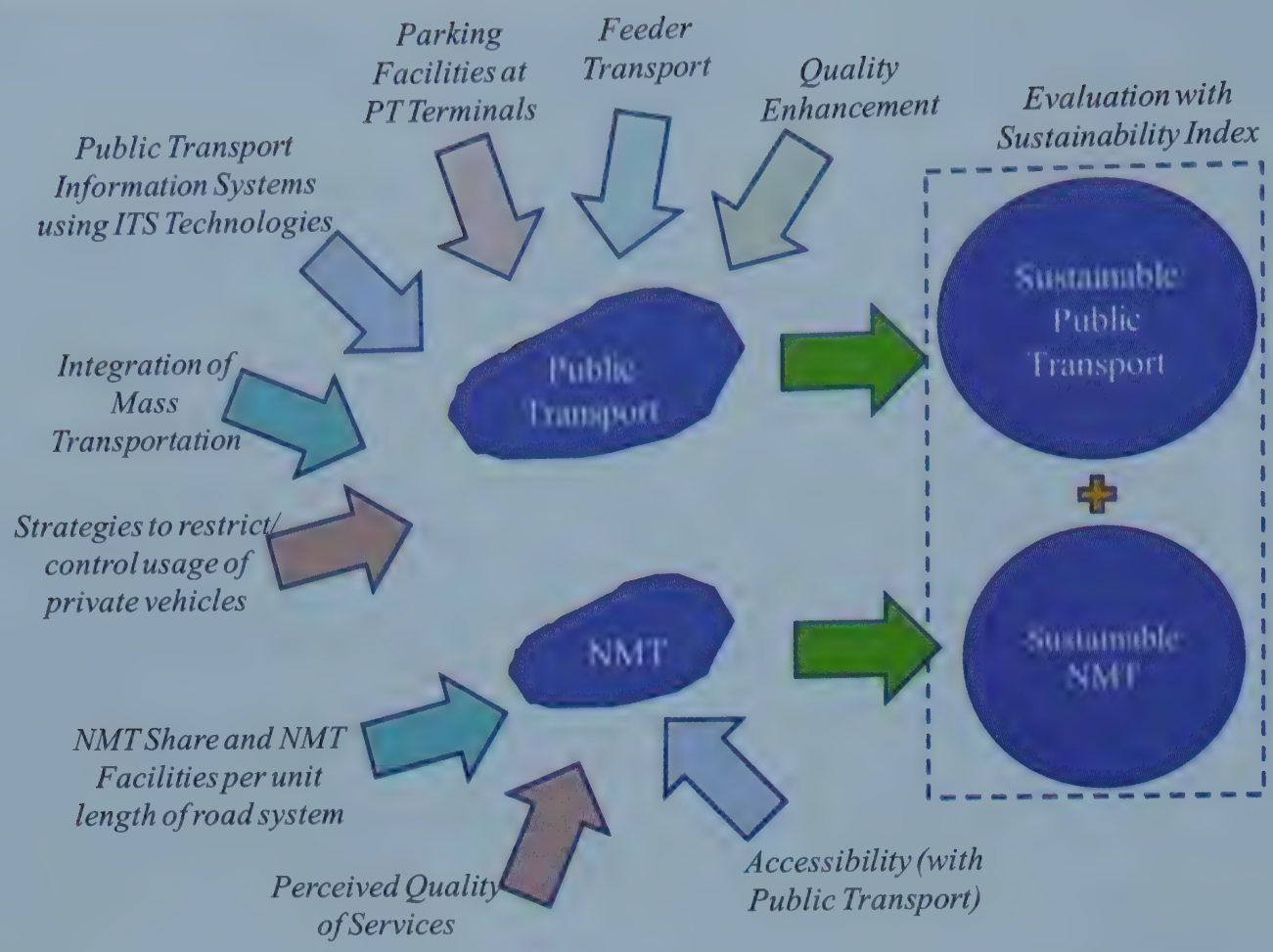

Parking Facilities at PT Terminals
Feeder Transport
Quality Enhancement
Evaluation with Sustainability Index
Public Transport Information Systems using ITS Technologies
Integration of Mass Transportation
Strategies to restrict/ control usage of private vehicles
Public Transport
Sustainable Public Transport
NMT
Sustainable NMT
NMT Share and NMT Facilities per unit length of road system
Perceived Quality of Services
Accessibility (with Public Transport)

Fig. 1.2 Broad Framework to develop Sustainable Transportation System

It can also be seen from the **Fig. 1.2** that the NMT has to be integrated and implemented along with public transport systems to make entire system as sustainable. A good evaluation system such as Sustainability Index should be there in order to continuously evaluate the performance and check suitability of new policy measures from time to time for efficient operation of sustainable transportation systems.

2. GUIDELINES FOR SUSTAINABLE PUBLIC TRANSPORTATION SYSTEM

2.1 Quality Enhancement of Public Transport System

Public transport holds center stage in the urban transport agenda. A well-functioning and sustainable city cannot be achieved without strengthening its public transport system. Infrastructure plays a vital role in the operation of an efficient, convenient and safe transit. The steps involved to enhance quality of public transport systems to achieve sustainability are as follows:

- Identify the parameters for evaluation of service quality using RATER Model (typical parameters identified for bus and sub-urban trains systems are given in **Table 2.1**)
- Using techniques such as Important Performance Analysis (IPA), Customer Satisfaction Index (CSI) etc., the parameters required for improvements can be selected

- According to the identified parameters, the improvement policies shall be formulated and implemented to enhance the quality of the public transport system.

The other points which need to be focussed to enhance quality of public transport are as follows:

- To attract the passengers towards bus transportation system: the frequency, cleanliness of buses & bus stops and management of crowd during travel should be given top priority
- To retain the existing users of bus transportation, following parameters should be given high consideration: bus fare, good on-board facilities for passengers including those facing any disadvantage, staff behaviour, seat priority for specific segments of population (senior citizens, disabled persons, woman, children), stopping of bus at exact bus stop location and proper installation and functioning of electrical equipment's (Fan/Light)
- To attract the passengers towards Sub-Urban railway/MRTS the parameters namely personal safety onboard and at station, cleanliness of trains and stations, proper access system integrated with rail system, minimum service time including interchange, etc. should be given top priority

Table 2.1 Typical Quality Performance Indicators of Public Transport System

Public Transport System	Quality Performance Indicators
Bus Transit System	1. Personal Safety on Board 2. Personal Safety at Bus Stop 3. Cleanliness of Buses 4. Cleanliness of Bus Stop 5. Bus Stop Maintenance 6. Crowd during Travel 7. Comfort during Travel 8. Functionality of Electrical Equipment's (Fan/Light) 9. Bus Fare 10. Frequency of Buses 11. Regularity/Punctuality of Buses 12. Parking Facilities 13. Facilities for Disabled People 14. Information Dissemination at Bus stop 15. Information Dissemination On-Board 16. Availability of Schedule/Map at Bus Stop, App, Booklets 17. Complaint Registration/Redressal Facilities 18. Periodicity of Ticket Inspection

	19. Bus Helpline Information 20. Behaviour of Bus Conductor 21. Seat Priority for Woman, Children, Senior Citizen and Disable People 22. Bus Stopping at exact Bus Stop Location 23. Complete Stopping at marked space of every Bus Stop 24. Utilities at Bus Stop (especially at Major Stop) – Bin, Water, Urinal, etc. 25. Availability of Benches, Shelter at Bus Stop 26. Quality of Seats, Standing Comfort and Accessories 28. Panic/STOP button at every seat 29. Bus On-Board Quality (Low Floor or High Floor) 30. Driver's Driving Behaviour (Over Speeding)
Sub-Urban Rail Transit System/MRTS	1. Personal Safety On-Board 2. Personal Safety at Station through CCTV Cameras 3. Cleanliness of Train 4. Cleanliness of Station 5. Cleanliness of Toilet Facilities on Train/Station 6. Availability of Seats at Station 7. Crowding On-Board 8. Comfort On-Board 9. Functionality of Electrical Equipment's (Fan/Light) 10. Train Fare 11. Frequency of Train 12. Regularity/Punctuality of Train 13. Parking Facilities 14. Facilities for Disabled Persons, Children, Woman and Elderly 15. Luggage Facilities On-Board 16. Information Dissemination at Station 17. Timely Information Announcement and display at Station 18. Complaint Registration/Redressal Facilities 19. Periodicity of Ticket Inspection 20. Schedule and Movement App, Booklets 21. Entry/Exit/Interchange Facilities – Efficiency, Optimized Flow 22. On-Station Service Time 23. Behaviour of Staffs' Personnel

- To retain the existing users of Sub-Urban railway the factors like fare, availability of seats at station and in train, electrical equipment on-board, information dissemination at station, timely information announcement and display at station should be given due consideration.
- Seamless and integrated payment system for all public transport services. Unified Metropolitan Transit Authority (UMTA) could be a solution for it.
- Privacy is one of the very major concerns for a specific segment of society that creates hesitation in using public transit. Hence, provision of seating with adequate privacy may be designed on-board.
- Seat priority shall be given to women, children, senior citizen, disabled or any person facing certain disadvantage.
- Services with differential level of passenger services can be operated to enhance comfort level and experience, which may help in attracting people from a special segment of society which currently prefer private transportation. The fare price may vary to accommodate the quality of service provided on-board.
- Good public transport can reduce car dependency and improve the environment for everybody, particularly in residential and commercial areas. Road spaces must contribute to a high quality public transport and should not be designed primarily for the movement of private vehicles.
- Design of the public transport should be attractive to passengers, including those who have the option to use a car, and should be efficient and economical for its operator. This involves designing the public transport and pedestrian routes at the same time as well as facilities for car parking. The bus routes need to be progressive without diversions into loops, bus stops or stations need to be as near as the doors of destinations, the footpath and cycle route network to the stops or stations needs to be direct and of high quality etc.
- Public transport can compete with the car on routes where it can offer an attractive service. This requires a package of measures, including quality public transport, bus priorities, park and ride services and encouraging the use of public transport, walking and cycling.
- To attract passengers, a public transport service must satisfy travellers' requirements. It must serve routes that should connect major origins and destinations of trips, offer a high frequency service, be reliable and quick, having good quality vehicles and courteous staff and be affordable. To be viable, the service must not incur ongoing costs greater than its revenue.
- Public transport must provide a high quality product to attract car users.
- The target market for public transport must be the whole of the population, rather than the non-car owners who constitute traditional bus users. The design of a development must cater for the needs of travellers walking to and from a bus stop, waiting for the bus or cycling to a railway station. These parts of journey have a major effect on the attractiveness of public transport.
- Public transport can only attract and retain passengers if the services it offers

meets the expectations and satisfaction level of travellers, and are of a sufficiently high quality. But simply providing the services is not enough, on its own, to attract passengers.

- Lack of information about service is one of the major barriers to public transport use. Providing information to potential passengers is an adjunct to a good managed public transport service. Network information should provide a route map covering all the services in an area with basic service details. Service information providing timetable and route information for a single service or group of services is vital. Information at bus stops is important as this is often the first point of contact with the network. Real time information can give confidence in the service.
- A major/main haul of public transport mode provides the opportunity for a higher density of development. High density, high trip generating activities should be located in areas of good public transport accessibility. Policies and standards for parking should also reflect accessibility to public transport.
- Soft policy measures to alter the travel behavior of private transport users and induce a modal shift towards public transit like Voluntarily Travel Behavior Change (VTBC) in Australia or Travel Feedback Plan (TFP) in Japan. Nudge theory and urban design interventions can be very useful for this purpose.
- Well planned place making of public transit stations helps in increasing ridership.

2.2 Sustainable Feeder Transport System and Parking Facilities at Public Transport Terminals

A multi-modal transportation system with seamless feeder transport and planned interchange and parking facilities is highly required as it would ensure the use of public transport to its best potential. The planners and authorities having such planning guidelines can aim for designing and implementing such multi-modal sustainable transportation system. It will cater to public transport security, safety and emergency/disaster management, noise pollution and abatement measures for urban transportation, integrated ticketing, seamless travel across modes and intelligent transportation system. The steps involved to implement sustainability are discussed under feeder transport and parking facilities at public transport terminals in the subsequent sections to improve understanding of the significance of sustainable public transport system with efficient seamless feeder system at public transport terminals.

2.2.1 *Sustainable Feeder Transport System*

The following are the steps to design optimal feeder network:

- Demarcate influence area for Non-Motorised Transport (NMT), Intermediate Public Transport (IPT) and Public Transport (PT).
- Locate the feeder network to the metro station covering the attraction point situated in the area, where large assessment of the commuters is available.
- Develop the feeder service-based access-route maps and install at prime locations. These may also be accompanied with PT service information kiosks for readily available information on services available in the area.

- Consider the plan of the existing roads to adjudge the movement of the feeder bus to attract large numbers of commuters to use the system.
- Estimate the number of feeder service (minibus, share auto etc.) required for each route taking into consideration the frequency of the mass rapid transit per hour and the loading to be catered by the system.
- Appraise the necessity of integrated transport system with regard to the willingness of commuters in the area.
- Calculate the travel time of feeder bus, evaluate the occupancy of public transport trip.
- Estimate the requirement of separate feeder bus with par to public transport service currently operating in the area.

a. Demarcation of Influence Area

The Catchment Area with 1 km, 2 km, 3 km and 5 km zones for Pedestrians, Bicyclists, IPT mode and buses should be considered respectively at each metro station by drawing the travel distance from the centroid of the station. **Fig. 2.1** shows marking of typical catchment area for various feeder modes at metro station.

b. Site Reconnaissance Survey

The survey should capture:

- road characteristics like available Right of Way (ROW) and carriageway width
- land use in the site vicinity
- identify the major establishments
- trip generators and
- locations of the major infrastructures in the locality

Fig. 2.1 Typical Description of Catchment Area for various Feeder Modes at Metro Station

c. Traffic Volume Survey

- The traffic volume survey at intersections in the vicinity of terminal shall be carried out to calculate the Volume-Capacity (V/C) ratio so as to know whether is it feasible to run feeder vehicle in the route.
- Both peak hour and off peak hour volume can be taken and V/C ratio be calculated based on the ratio of peak hour volume and the standard capacity values for different category of roads.

d. Commuter Opinion Survey

- Opinion survey elucidates the opinion of the people regarding their willingness to use the feeder service to catch the metro, type of feeder service they are likely to use, and the amount they are willing to pay for the journey.
- The survey can also be used to do a SWAT analysis for the access travel modes and paths, PT routes and services and NMT routes and services available in the area.
- This survey plays an important role in deciding the type of feeder services in the area.

e. Mapping

The mapping consists mainly of two stages:

(i) Location of Station:

- The stations can be located by drawing a series of circles measuring 250 m radius throughout the study area. This helps in allocating the position of the station where people can merge through 250 m from all the sides as shown in **Fig. 2.2**.
- Once the circles are drawn, imaginary center points can be marked such that the center to centre distance from the circles will be 500 m. Based on the centre points a grid network can be considered and these points are referred as base points where the feeder service needed to be provided.
- Considering the existing road network pattern and the identified base points, the nearest feeder service bus stations can be proposed.

(ii) Alignment of Routes:

Next stage is to locate the feeder routes keeping in view the following:

- The route should not have V/C ratio exceeding 1
- The connectivity should attract more number of trip makers
- It should connect some of the important nodes following shorter travel time route so as to get the higher trip numbers

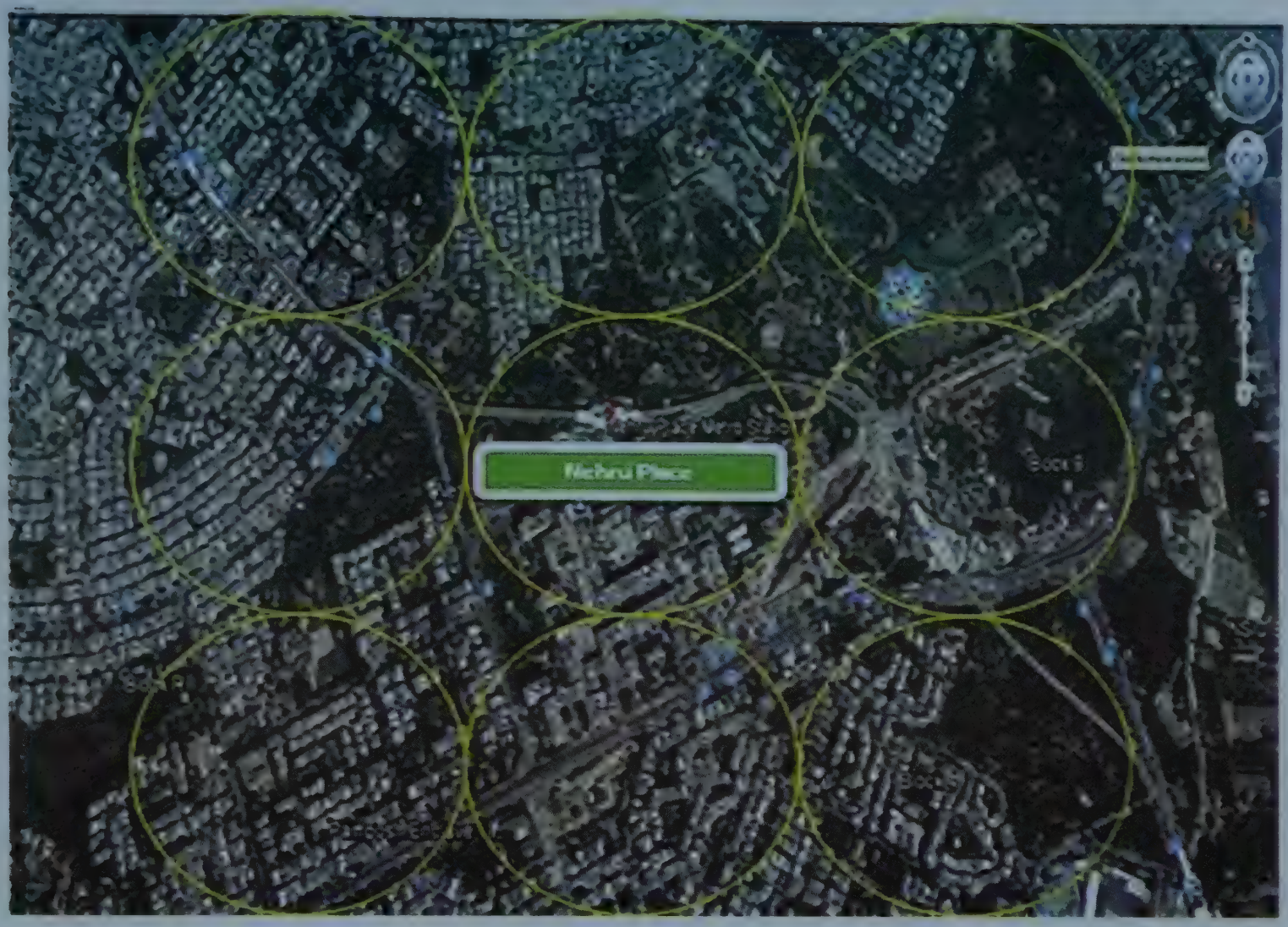


Fig. 2.2 Typical Description of Location of Stations by drawing a Series of Circles of 250 m radius at Metro Station

f. Estimation of Travel Time

The time required for the feeder bus from the farthest distance of the proposed route to the metro station should be essentially lesser than the existing public transport, so that the commuters will use feeder bus to catch the metro. Example calculation with certain assumptions to calculate travel time is given below:

- If, the speed of the feeder bus is 20 kmph, additional 5 min may be considered as time for starting back the bus at the feeder bus station. The total travel time is calculated using following formula:

$$\text{Travel Time (in Min.)} = \frac{\text{Distance (in km)}}{\text{Speed (in km)}} * 60 + 5 \qquad (2.1)$$

g. Estimation of Number of Feeder Buses and Trips

Calculation of number of feeder buses can be made based on certain assumptions:

- People using IPT and private modes may shift to Feeder buses ensuring reliability and accessibility.
- Capacity of the feeder bus being 18-20 passengers.
- 70% of the total feeder buses will run on the routes where trip rate is high and 30% of the feeder buses on routes where there is less trip generation.

- The number of commuters at any station is the summation of boarding and alighting passengers. Therefore the loading of commuters at a particular station is considered as 50% of the total number of commuters.
- The number of trips required for feeder bus on each route can be calculated from total passenger demand, capacity of feeder bus, and frequency using the following formula:

$$\text{Total trips of feeder bus on each route} = \frac{\text{Total trip makers using feeder bus}}{\text{Capacity of feeder bus} * \text{Frequency}} \quad (2.2)$$

h. Finding Optimal Route

If routes are designed only along the shortest path then such routes are likely to have fewer nodes than longer path and consequently, their contribution to the demand satisfied is likely to be less. However, if a route connecting is along a short (but not necessarily the shortest) path, it might satisfy a higher share of the total demand (achieving certain minimum level of ridership) with only a small increase in the total trip time. This is desirable from the operator's point of view. But, at the same time, the users' perspective warrants the routes to be as short as possible so as to minimize their travel time. So, the problem is to obtain a route configuration, which will optimize these conflicting objectives. The schedule-co-ordination problem is formulated as a combinatorial optimization. The objective function need to be fixed as minimization of sum of operating cost of buses (operator cost) and waiting time cost of passengers boarding along the feeder routes (user costs) subject to load factor constraint.

2.2.2 *Various Possibilities of Different Modes as Feeder Systems for PT*

Firstly, the characteristics and demand of the feeder modes need to be understood by carrying out appropriate field surveys. Based on the estimated demand and characteristics from the surveys, the possible feeder modes have to be designed.

a. Pedestrian

- Generally, around 46-50% of metro trips depend on walk mode for the first and last-mile connectivity which include both from home to metro and from metro to destination. Safe pedestrian infrastructure of 1 km in the periphery of metro station will be the most acceptable mode as feeder systems. It can be extended up to 2 km.
- Sky-walks/Subways shall give direct access and landing into the nearby office and shopping complexes, malls, school buildings, multiplexes, etc., apart from facilitating safe crossing of junctions.
- Development of pedestrian route surrounded by green cover, an amphitheatre and a shopping arcade can best utilize the urban space.
- The other pedestrian facilities at/around metro stations have to be adequately and appropriately provided as given below:
  - Footpaths need to be continuous and height of footpath should be as per relevant IRC guidelines.

- In case, discontinuity occurs due to the presence of driveways in front of residences, cross-streets, etc. the flushing of footpath need to be done with such facility in order to maintain continuity.
- All the encroachment on footpaths which cause pedestrians to walk on the carriageway and get exposed to risks from fast moving traffic should be removed. In case of other street furniture, trees, construction materials, potholes, manholes, etc., the widening of the footpath on the other side of the carriageway might be considered so that the pedestrians need not to come on the carriageway.
- Adequate pedestrian infrastructure along the roads and at metro station entry gates including barrier free ramps for disable people needs to be provided to access metro stations.
- In case where the entry of the metro station is located at mid-block, dedicated pedestrian signals or zebra crossings need to be installed.
- Adequate and proper illumination shall be provided on the footpaths.

b. Bicycle

- Around 15-17% of metro trips are using bicycle to access the metro stations at their origin (from home to metro station) for their last-mile connectivity usually in the residential areas.
- Bicycle-to-transit services (trails, on-road bike lanes, and bike parking) enlarge transit's catchment area by making it accessible to travelers who are beyond walking distances from transit stations.
- People are willing to use bicycle and their usage may increase if these are available on rent and bicycle can be used to reach their destination from metro station as well.
- Better bicycle infrastructure may encourage bicycle users to opt for this NMT mode as feeder systems.

c. Pedestrian & Bicyclists Infrastructure

A pedestrian and bicyclist friendly environment is the most fundamental and essential requirement of any catchment area. If investments made in developing high quality public transport systems are to be efficiently utilized, pedestrian access to public transport must be given highest priority. All arterial and sub-arterial roads should be made pedestrian friendly within the catchment area of 1 km and upto 2 km for cyclists to/from metro station.

(i) Pedestrian Track

a) Since the pedestrian flow is determined by land use, the sidewalk widths can be designed as per the carriageway width as per IRC:103

Residential Areas: 1.8 m to 2.2 m

Commercial/Mixed Use Areas: 2.5 m - 4.0 m

In addition, a requisite "dead width" of 0.5 m is to be added to all pedestrian tracks.

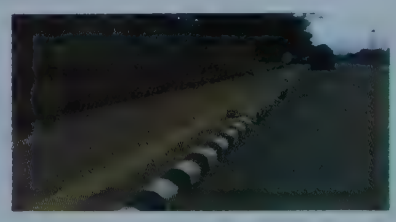
b) Obstruction Free walking zone of minimum 1.8 m width is required with no utility ducts, utility poles, electric, water or telecom boxes, trees, signage or any other kind of obstruction falling on the pathway.

c) Creation of commercial/hawking zones at every 500 m to encourage walkability, increase street activity and provide safety. Hawkers must be given designated space within the road right-of-way so that they don't occupy pedestrian walking area.

d) Provide dustbins, postboxes, signage and other public amenities at street corners for high usability.

e) Provide Accessible Public Toilets at every 1 km distance preferably close to bus stops for easy access by pedestrians and public transport users.

f) Avoid sidewalk interruptions by minimizing kerb cuts i.e. minimize the number of driveways that cross the sidewalk in order to support pedestrian safety and a continuous sidewalk.



g) Kerb heights on all roads should not be more/less than 150 mm.

h) Kerb ramps must be installed at all intersections and mid-block locations where pedestrian crossings exist. Standard kerb ramps' width should not be less than 1.2 m at a gradient no greater than 1:12 as per IRC:103.

i) Sidewalks and crosswalks should be fully navigable by the physically challenged.

j) Provide at-grade crosswalks at maximum distance of 250 m aligning with location of transit stops, type of street/land use activities and neighboring building entries and destinations.

k) Provide raised table top crossings with flat surface preceded and followed by gradient at 1:15 in the direction of travel and minimum 20 second pedestrian signals for a roadway width of 20 m to allow pedestrians, cyclists and physically challenged people to cross from kerb to kerb.

(ii) Bicycle Track

a) The Bicyclists track can be designed as per carriageway width:

Arterial Roads (>40 m): Segregated cycle tracks required with minimum 2.5 m width for two-way movement.

Sub-Arterial Roads (40 m-20 m): Segregated cycle tracks with minimum 2.5 m width or traffic calming measures required if segregated track not provided.

Local Streets (<20 m): No special feature

b) In case of segregated footpath and Bicyclists track, Bollards should be provided with clear gap of 1.2 m and 1 m height on sidewalks to prohibit the entry of motorised two wheelers.

c) On arterial roads, 0.5 - 0.7 m minimum landscaped buffer should be kept between pedestrian and bicyclists lane and motorised vehicle lane in order to maximize the speed, efficiency and capacity of the pedestrians and cyclists.

d) The pedestrian and bicyclists lane should be constructed with good skid resistance cement Concrete or Asphalt in order to ensure a low maintenance and smooth riding surface. It can be skid resistant tiles in combination with tactile tiles placed strategically.

e) Continuous tactile guide which has a different texture to the rest of the footway must be provided for vision impaired persons at footpath with minimum 300 mm width and minimum 300 mm from edge of footpath.

f) Light Emitting Diode (LED) pavement markers should be properly marked to improve the safety of intersection approaches as well as pedestrian, bicycle, and others crossing. Markers will improve drivers' awareness especially in low visibility conditions.

g) Provide adequate Street Lighting for pedestrians and bicyclists (approx. 30 lux-level is suitable for both non-shopping areas and shopping areas).

h) Enforcement and Traffic Calming required with presence of speed humps or rumble strips on all arterial and sub arterial roads.

d. Cycle Rickshaw/E Rickshaw/Auto Rickshaw/Gramin Sewa

- Rickshaws are an important low cost feeder mode for metro users. Nearly 18-23% of metro trips depend on Intermediate Public Transport (IPT) within 3 km of catchment area for their last-mile connectivity.
- Systematic IPT/rickshaw parking near metro stations are required to facilitate the use of rickshaws for access and egress trips at metro stations.

e. Feeder Bus

- About 8-9 % of metro trip depends on feeder services for first and last mile connectivity which include both from home to metro and from metro to destination.
- An ideal feeder route length should range from 3 to 5 km. An increase in route length may result in very high round trip cycle time and high operating km and reduced service reliability.

- The connection to multiple stations makes the route unreliable and highly vulnerable to congestion.
- Service reliability of a route is a key characteristic that may influence ridership.
- Optimal feeder bus route with high frequency may lead to better use of this low cost mode as feeder services.
- The passenger capacity of a feeder bus service shall not be more than 18-20 passengers.

f. Transit Infrastructure

Mass transportation options serving the influence area should be well integrated with each other, as well as, with the pedestrian and bicycling networks, so that the time spent in modal transfers is minimum. Commuters' catchment area from metro station is 3 km for Intermediate Public Transport (IPT) modes and up to 5 km for feeder buses. Modal transfers should be integrated through ticketing and information. Provision of feeder modes at metro stations should be strictly based on transport demand and supply. Considering that actual ridership per day at metro stations is known and considering that metro trains run at a frequency of 'T' minutes from 6:00 AM to 11:00 PM (i.e. 17 hrs), the total alighting commuters demand 'D' for feeder modes per arrival of each metro can be estimated as follows:

$$D = \left[\frac{\text{Alighting Commuters per day*T}}{17*60}\right] \quad (2.3)$$

Similarly, alighting of commuters on arrival at each metro station in peak period, D' can be estimated by:

$$D' = \left[\frac{\text{Average Alighting Commuters in Peak Period*Frequency of Metro in Peak Period T'}}{\text{Peak Period*60}}\right] \quad (2.4)$$

Supply side characteristics include the capacity of existing and planned transportation system infrastructure for all modes of travel for the movement of people. Total supply of feeder mode *'S'* per arrival of metro should be as follows:

$$S = \frac{\text{[Percentage of mode choice * D']}}{\text{Average Occupancy}} \quad (2.5)$$

Therefore, total transport supply per day at metro station should be permitted accordingly. The following other options should also be included in order to encourage seamless travel:

- Seamless integration of all transit modes with Metro by unified ticketing and adequate signage is required. Common mobility card can be issued integrating Metro, feeder bus and parking.
- Feeder buses should be in good condition, GPS enabled with CCTV and common mobility card.

2.2.3 *Design of Advanced Parking Facilities for Different Vehicles including NMT at Public Transport Terminals*

Equitable provision of parking for different feeder modes and traffic management plan at and near mass public transport/metro terminals is the prerequisite of a sustainable feeder transport

system. The demand needs to be estimated from feeder transport survey and that can be utilized to estimate parking/circulation demand of various feeder modes. Further to understand the characteristics and demand for parking by private vehicle users namely car, two wheeler and bicycle, the parking accumulation and parking duration surveys need to be carried out for both organised and unorganised parking areas.

This will allow the optimal design of parking and traffic management/ circulation as given below:

a. Bicycle Parking

- First preference may be given to provision of bicycle parking either free or at nominal rate at ground level of the station.
- Provide cycle rental stands at metro station and also at nearby important destinations, like schools, civic buildings, large offices, malls, etc. and provide information signage at both end locations.
- Provide bicycle taxi services for those commuters who do not want to bike or do not know bicycling but want to use them for being sustainable. This will also help in generation of employment.

b. Two Wheelers and Car Parking

- Adequate parking facility for private mode such as two-wheelers and cars users, who are going to use metro for their journey, may be provided at Terminal Stations and major interchange stations depending on the availability of area. Based on the demand, the different types of paid parking facilities namely, underground, elevated, at grade parking space as per station condition can be considered. This can also be attached with common mobility card for seamless journey.
- Off-street long term public parking facilities shall be provided and preferably be located not more than 500 m from the centre point of the Metro Station entry gate to avoid congestion.
- In order to reduce interchange time and to enhance efficiency, multi-level parking may be considered for both at metro station parking (can be inside station building) and at off-street public parking areas nearby.
- Further, advanced parking management and information system may be employed at these parking facilities. It may have provision of automatic entry/exit control for entry pass/ticket and parking fee collection based on parking duration, parking way indication (inside the parking area) and management system, display of availability and utility of parking spaces (at a particular time) at gate and approach roads to the metro station/bus terminal.
- Provision for partly or fully mechanized automatic multi-level parking may be explored depending on the demand and availability of space.
- Either demand-based parking charges or fixed parking charges based on the opportunity cost of the land shall be considered for promoting the use of public

transit feeder services. If the parking charges are further used for the improvement of last-mile public transit feeder services, then this might act as a double dividend mechanism.

c. Intermediate Public Transport Parking

- Many commuters rely on the intermediate public transport services for their last-mile connectivity. These services provide alternate mode of access and hence shall be located as near as possible to the exit gate of stations/terminal buildings.
- The parking space may be created by flaring the road width so that these modes do not interfere with the through traffic on the main carriageway.
- These vehicles be parked parallel to the kerb side so that passengers can alight the mode easily without having requirement to mingle with other motorised traffic which may be hazardous.
- Separate parking space for mobility on demand services shall be created to pick up the passengers from the station or to drop the passengers at the station.
- The lane width for IPT can be kept as not more than 2.5 m.

d. Traffic Management/Circulation Plan

- Cycle Rickshaws may be given top priority for access to the metro station in order to encourage non-motorized/green transport by providing segregated entry lanes and designated halting place (boarding and alighting ways depending on demand) just in front of the metro station.
- Second priority for access to the metro station may be given to bus feeder system in order to enhance efficiency and sustainability. Direct entry/exit to the station area and designated halting place (boarding and alighting ways depending on demand) be provided close to the gate of the metro station/bus terminal.
- Third priority regarding circulation and access to the metro station may be given to IPT modes comprising of E-Rickshaw and Gramin Sewa.
- Fourth priority for circulation and access to the metro station may be given to other IPT modes comprising of taxi and auto rickshaws.
- Designated halting place (boarding and alighting bays) for each permitted IPT operator and Metro feeder bus on equitable bases may be provided as per the demand, priority policy and capacity of metro terminal in order to encourage sustainability. Appropriate traffic management/circulation plan need to be prepared for each metro station and should be strictly enforced along with lane discipline.
- Advance public information system be designed and provided at the metro stations in order to provide information of the feeder transport system, and parking and traffic management system. The information may be provided at appropriate places at stations, approaches, waiting area, parking, boarding/alighting, platform, exits etc. Information include display map of 5 km influence zone around stations showing road network with place names, major landmarks and destinations and location of all the feeder mode facilities within and outside station premises, schedule and fare chart of each feeder mode, on-line/off-line arrival/departure/availability of each

feeder mode, and options and guide to choose a particular mode based on location, distance, travel time and fare.

e. Advanced Parking Facilities at Metro Station

The following facilities at metro station need to be considered:

- LED Display with information about various feeder modes available at Metro Station.
- Advanced parking facility for Car, Two Wheeler, Bicycle to encourage Park and Ride Facility.
- Frequent Feeder Bus service with designated Bus bay to avoid congestion.
- IPT modes as per the metro ridership and space available should only be allowed to park outside metro station. They should strictly park in designated lane on first come first serve basis.
- Rented Bicycle facility may be provided at Metro Station to encourage NMT modes.
- Disabled friendly Infrastructure must be put in place to attract differently abled people to use Public Transport.

2.3 Advanced Public Transport Information Systems using ITS Technologies

The efficient use of public transport systems depends on frequency of services, fare, seat availability and real time information of the public transport. Usually, frequency and fare is considered to be most significant to satisfy the people. However, if the user does not have information about the availability of seats and at what time they can get the service (arrival time), the users have to wait for unknown time at bus stops and even if they wait, there is no guaranty of getting seat in the public transport. As the value of time is increasing in urban areas day-by-day, the urban travelers are facing problem of making decision for their journey due to non-availability of public transport information in terms of their availability and time of arrival at the user place. This information is going to be very useful to avoid waiting time at bus stops and also to take the decision of mode choice by which user has to perform the journey. In urban areas, even though bus schedules are fixed, one cannot guess the location of the bus on a particular route due to high traffic congestion. In order to inform the commuters to plan their departure time to reach public transport boarding point, the real time information is necessarily to be communicated through Advanced Public Transport Information Systems (APTIS) using Intelligent Transport System (ITS) technologies. In this way, the services to public transport users can be improved by providing the dynamic information of the buses on the network and attract the people to use the public transport system in order to reduce the private vehicle usage. However, there is always been some ambiguity on what kind of ITS technologies that a city should have based on population, technology usage by people, system implementation costs etc. as there are varieties of technologies being developed in the domain of information technology and number of vehicle tracking systems are available over the globe. Considering this, the points to be considered to evaluate the appropriateness of suitable ITS technologies in terms of Advanced Public Transport Information System (APTIS) and policy guidelines for Indian conditions are given below:

1. The success of APTIS depends on availability of technology in the area in terms of modes of access to the information. The sample survey of the public transport

users shall be carried out to know the modes of access available with passengers, capability of usage by passengers, probable percentage of people who will be using it in the event of implementation, prevailing waiting times at bus/metro terminals etc.

2. The specification of the system going to implement in the area in terms of budget, maintenance, accuracy of information dissemination etc. along with share of public transport trips in total trips, size of the city, and an absolute number of trips, average income of commuters, etc. shall be obtained.
3. The total savings of all passengers of public transport shall be calculated in terms of total savings arising out of reduction in wait time/total travel time and converted into cost by multiplying with average wage rate of passengers.
4. The total system cost shall be determined by adding initial cost and maintenance cost and capital interest thereof.
5. The breakeven period which matches the system cost and system benefits can be determined and can be examined whether it is acceptable or not.
6. There may be other benefits like shift of private trips to public transport trips which further improves the environment.
7. Once the APTIS qualifies for implementation, its success will be dependent up on the accuracy of information and campaign of the system, including short training of the passengers at terminals, stops and at large gathering places to explain the usage.
8. The system may not be viable or successful in small cities less than 10 lakh population or size less than 150 sq.km.
9. In case of LED displays at bus stops, it shall display the expected buses with arrival times within next 15 minutes. If the space is not available, it can scroll so that the passenger can benefit to choose the other routes for their destination.

2.4 Policy Level Sustainable Strategies to Restrict/Control Usage of Private Vehicles

The car ownership and car usage is increasing at an alarming rate in Indian cities and similar is its role in increasing the congestion, pollution and accident rate. Hence, there should be a definitive policy initiatives for regulating car ownership and its use in India. Even though the National Urban Transport Policy focuses on public transit usage and pedestrianization of cities, but in the absence of policies for restraining car ownership and usage, these efforts have proven futile. The expert opinion survey reveals that Vehicle Quota System would be the most suitable policy option to achieve the objective of car ownership restraining followed by the option of increasing Taxes on Cars from the relevance and feasibility point of view. Further, Congestion Pricing, Parking Charges, Car Pooling and Park & Ride would be the most suitable policy options to achieve the objective of car usage restraining measure.

The policy measures namely hiking in parking charges and variable parking pricing will have more impact in reduction in travel demand in long run considering the practical implementation. In case

of congestion pricing, to implement this measure, it requires lot of road infrastructure updation and changes in vehicle related infrastructure. Hence practical implementation is difficult in Indian conditions. However, to implement congestion pricing, considering the other areas/places, the user benefits relating to the covering area and travel time saved, the optimum congestion fee shall be determined. The vehicle rationalisation policy such as Odd-Even, in short run will have higher travel demand reduction. However, this will get nullify gradually over the years. Based on the analysis, merits and demerits of each policy are given in **Table 2.2.**

Table 2.2 Merits and Demerits of Different Vehicle Usage Restriction Policy

Policy Measures	Congestion Pricing	Parking Charging	Vehicles Quota System (Odd/Even Policy)
Expected Reduction in Travel Demand	20% Reduction in Car Users	26% Reduction in Car Users	15 to 30% Reduction in Car Users
Equity among Road Users	Low Income group have dis-benefits compared to High Income group	All users are better off Except those who park for higher duration	All users are better off Except potential Car users
Implementable	Filed implementation is difficult(*)	Implementable (***)	Implementable (**). In Long run reduction in cars may reduce
Sustainable	Sustainable (*)	More Sustainable (***)	Somewhat Sustainable (**)

*** higher star rating, higher the benefits

Another policy option is to integrate the direct and indirect cost of usage of a vehicle by a user. Internalisation of indirect costs like cost for abatement of air pollution, health related social cost, etc. will help in reducing the vehicle usage. It will be more equitable as it will not add to the persons who are not using motorised vehicles or are using non-motorised vehicles. These components can be in the form of environmental cost, social cost, marginal cost, etc.

2.5 Integration of Mass Transportation System through Travel Demand Modelling

For a growing economy like India, there are changes in the pattern of traffic demand for various modes of transport and secondly, the costs at which the newly generated demands are met by the diverse modes of transport. While a journey from one place to another actually involves more than one mode, the policy and decision-making is oriented only towards the main section of the journey (for example the rail or flight journey). The development of integrated transport reduces the cost of transportation substantially as it allows the various modes of transport to play their part in the most efficient manner, thereby leading to the higher utilization of capacity. Thus, once the integrated transport system is in place, the high capacity modes of transport are able to reduce their cost of operation relatively faster.

It is, therefore, important that for purposes of policy planning, the transport system must be viewed as an integrated structure in which various modes complement each other and not compete with each other. The study on public transport integration must be based on the requirement that the

passengers must experience a seamless cohesion between different modes of transport while being able to access longer distances.

For developing an Integrated Public Transport System, the following steps need to be considered:

- Study of the existing public and private transportation system and travel patterns
- Performing four stage travel demand modelling using high accurate techniques
- Developing scenarios of integrating mass transport systems, and
- Study on the impact of developed integrated transport system under different scenarios.

2.5.1 *Study the existing Public and Private Transportation System and Travel Patterns*

For this purpose, the data collection through following scientific travel surveys need to be carried out to understand the travel behavior of the commuters at the network level:

- Data Collection through Household Interview
  - Household Information
  - Socio-economic Data
  - Trip Information
  - Road Network Data
  - Secondary Data
    - Bus Route and Headway Information
    - Metro Rail Route, Time Schedule and Frequency Information

2.5.2 *Four Stage Modelling*

The travel decisions are formulated through sequential four steps:

- Trip Generation
- Trip Distribution
- Mode Choice and
- Trip Assignment

2.5.3 *Evaluation of Integrated Transportation System*

Different conceived scenarios can be evaluated by developed travel demand model and the effectiveness can be checked in terms of change in modal split, ridership, shift to PT from private modes etc. For this purpose, macroscopic simulation tools especially travel demand modeling tools can be utilised by creating the scenarios to evaluate before and after conditions in order to quantify the impacts emanated from the various transport policies. Depending upon the need and any particular type of transport policy desired to be analysed with micro level details, that can be evaluated with microscopic traffic simulation tools as well and quantify the impacts from the implementation of transport policies For instance, Ministry of Road Transport and Highways (MoRTH) has signed MOU with Australia University (UNSW) for setting up center of excellence for traffic stimulation modeling, thus realistic models can be expected from such an initiative

which can be utilized for evaluation and quantification of the impacts from the implementation of transport policies for Indian conditions.

2.6 Other Recommendations for Sustainable Transportation System

Other points to be considered for design and evaluation of sustainable public transport systems are given below:

- To support the development of viable integrated public transport system, it is essential that the accessibility needs to be improved.
- Shift needed from existing private vehicle oriented infrastructure to mobility oriented sustainable technologies.
- Multi-modal transit facility should be encouraged for seamless travel for commuters at Interchanges/terminals.
- Independent semi judicial body is required for periodical restructuring of fares to ensure the viability of the industry.
- Promoting the use of green technologies in public transport buses
- PPP mode development especially in urban transport infrastructure like integrated multi-modal mobility hub etc.
- Modification of schedules based on scientific traffic studies, route rationalization, increasing productivity/employee/bus, bringing down operational expenses, preventive mechanism/materials management needs to be focused.
- Shortest path to be ensured for pedestrians and bicyclists and must act as a network and not as separate entities.
- Way finding signs to be placed (within 1 km from terminal) displaying major points of interest and way to access PT terminals/stops in 3 languages (English/Hindi/ Local language)
- Vendor space allocation to be mandated to avoid taking over pedestrian space by vendors thereby bringing the pedestrian on the road reducing their safety
- Direct access from parking space to public transport station to be given priority along with space for 'accessible parking' at a spot nearest to station for ease of use for differently able commuters.
- In case of Intermediate Public Transport (IPT) modes, prepaid counters to be encouraged for IPT users.
- With respect to circulation plan, dead travel km to be kept minimum for better enforcement/acceptability.
- In case of APTIS, the SMS service for non-smartphone users also shall be considered for inclusiveness.
- In order to restricting private vehicle usage, better PT facilities shall be provided and private vehicle restricting strategies, bus priority strategies like BRTS, priority lanes, etc. shall be implemented.
- Bus stops and Terminals are to be user friendly and all the required facilities should be provided.

2.7 Evaluation of Sustainable Transportation System (Economic, Social and Environment) using Sustainability Index

Sustainability Index (considering social, environment and economic aspects) are standardized measures suitable for analysis in order to appraise the feasibility of a public transport policy. A standardized set of public transportation performance assessment is highly required for monitoring the implemented policies to achieve sustainability. The identification of most relevant set of sustainable and public transport performance indicators is going to play vital role which can be used to evaluate the effects of policy measures. The analysis of before and after from policy options implemented for various policies (such as Odd-Even policy, Electric vehicle penetration, increased frequencies of buses or introduction of feeder and metro services etc.) are needed to see the impact on sustainability with the utilisation of appropriate sustainability index in Indian conditions. In view of the above, to assess the sustainability of existing transportation systems in terms of deriving a Sustainability Index, following steps shall be considered:

2.7.1 *Selection of Relevant Indicators*

The selection of parameters often involves a trade-off between a limited set of indicators (using available data), that makes easier the collection and analysis phases, but may overlook important impacts; whereas, a larger set can be more comprehensive but have excessive data collection and analysis costs. Thus, the proposed list of indicators for the development of sustainability index shall be based on standard data measures available at city level or other scopes (i.e. Urban Master Plans). In general, all aspects associated with the traditional urban mobility planning shall be explored, while focusing on traffic management (through strategies to reduce congestion), transportation services (public transportation supply), transportation infrastructure (the urban road networks), and new green mobility concepts including non-motorized (cycling, walking, facilities and integration with mass transit) so that social, environmental, and equity issues are addressed into the process. Further, in the choice of parameters for sustainability index, the following criteria can be considered:

- *Comprehensive:* Indicators should reflect various economic, social and environmental impacts, and various transport activities.
- *Data quality*: Data collection practices should reflect high standards to ensure that information is accurate and consistent.
- *Comparable:* Data collection should be standardized so that the results are suitable for comparison between various jurisdictions, times and groups. Indicators should be clearly defined.
- *Easy to understand:* Indicators must be useful to decision-makers and understandable by the general public.
- *Accessible and transparent:* Indicators (and the raw data they are based on) and analysis details should be available to all stakeholders.

Accordingly, the following 17 indicators have been identified typically and classified in three categories to cater to the different aspects of sustainability:

- ***Environmental Effects***: (1) Energy Use and Consumption (2) Environmental

Quality (3) Noise Pollution (4) Renewable Energy Sources (5) GHG Emissions (CO_2, CH_4, N_2O, HFC, Total) due to public transportation system (6) Other Air Pollutants (Ozone, PM, NO, CO, HC) due to public transportation systems

- ***Social Effects:*** (7) Accessibility to Public Transportation System (8) Satisfaction with Public Transportation System (9) Safety & Security in Public Transportation System (10) Fatalities and Injuries due to Public Transportation System (11) Employment due to Public Transportation System
- ***Economic Effects:*** (12) Affordability of ticket fare of Public Transportation System (13) Household Expenditure allocation to Transport (14) Transport Emission Cost, Damage Cost and Mitigation cost (15) Transport Demand and Intensity (16) Crash Cost due to Public Transportation System (17) Transport Cost and Prices

2.7.2 *Data Collection*

Data for the typically identified seventeen indicators can be collected from mainly four information sources namely human experts, traffic observations, questionnaire surveys and models. Since the experts are generally from city transportation authority/planners having several years of experience with the city, their responses are deemed reliable. Surveys shall be conducted with the city residents/commuters and the responses can be aggregated.

2.7.3 *Utility and Weightage Estimation*

To start with, the selected indicators are to be kept under the three dimensions of sustainability. These selected indicators are measured by collecting data from various surveys (Qualitative and Quantitative) and all the indicators are to be homogenized into a single value (U) between 0 - 1. Homogenization need to be done to have a common index value for all the indicators in order to bring them into common units for comparison with other parameters, doing some mathematical operations and assumptions etc. In the present case of sustainability, some indicators would have positive effect and some indicators would have negative effect. For example, the transport demand indicator has positive impact on the final sustainability index value i.e. as the productivity increases, level of sustainability rises and vice versa. Similarly, energy use indicator has a negative impact on the final sustainability index value i.e. as energy use increases the level of sustainability decreases and vice versa.

Next is the process of weightage which involves emphasizing the contribution of indicator to their respective sustainability dimensions as a final effect or result. It means, that each indicator may not be contributing equally to the sustainability, hence some indicators are adjusted to show that their contribution is more than other indicators. This can be done by conducting an indicator importance or preference survey among concerned stakeholders (focused users, policy makers, service operators, service providers and experts) asking them to rate the indicators on the basis of their importance in measuring the present level of sustainability for the selected public transportation modes. The indicators are evaluated on a score ranging from 0 to 10, where 10 is the maximum importance. Other scales like Likert scale (0 to 5 or 0 to 7) can also be used. Subsequently, a weighted average can be taken for each indicator to find the individual weightage. The final value signifying the present sustainability index is calculated by aggregating the all weighted individual indicators in the range of 0 to 100. The maximum value is 100 with fully sustainable system and minimum value of 0 with no sustainability.

The final weighted individual utility value is the product of weights and homogenized value of the indicators as given below:

$$\text{Weighted Individual Utility Value} = W_i^* u_i \quad (2.6)$$

Where: W_i is the weight of 'i^{th}' indicator,

u_i is the homogenized value of 'i^{th}' indicator.

Analytical Hierarchy Process (AHP) is also another form of preferential survey technique available which collect importance rating from stakeholders and derive weight of the individual indicators in range of 0 to 1.

2.7.4 *Estimation of Transportation Sustainability Index*

The final sustainability index is the aggregated sum of weights and homogenized value of all the indicators (Cascajo, 2008). The estimated utilities are used to determine the system sustainability at any given time 't' using a Transportation Sustainability Index (TSI). Let us denote the global utilities for the 'N' indicators at time 't' by $u_1(t), u_2(t), \ldots\ldots, u_N(t)$, then the transportation sustainability index is given by:

$$TSI(t) = u_1(t) * W_1 + u_2(t) * W_2 + \ldots\ldots\ldots\ldots\ldots\ldots + u_N(t) * W_N \quad (2.7)$$

Where N represents total number of indicators

$u_1, u_2, \ldots u_N$ represent utilities for indicators

$W_1, W_2, \ldots W_N$ represent weightage of indicators

t represent time instant for base/existing condition

2.7.5 Impact Assessment

The impact of transportation measure on the city/system sustainability is assessed by observing the change in Transportation Sustainability Index (TSI) with respect to pre-implementation (t-1) and post-implementation (t+1) stages. The term 't' represent time instant in base/existing condition, 't-1' represent a time instant in pre-implementation stage and 't+1' represents a time instant in the post-implementation stage, then the change in transport sustainability index over time interval [t-1, t] is given by:

$$\Delta TSI(t, t-1) = TSI(t) - TSI(t-1) \quad (2.8)$$

If $\Delta TSI(t, t+1) > 0$ then the impact of transportation measure on the city is said to be positive and the measure is recommended for adoption. If $\Delta TSI(t, t-1) \leq 0$ then the measure can be rejected.

3. GUIDELINES FOR SUSTAINABLE NON-MOTORISED TRANSPORTATION (NMT) SYSTEM

3.1 Overview

The principle guideline for improving non-motorized trip share is to include it in every step of transportation planning and engineering work with equal priority (if not higher) compared to any personalized motorized vehicle on urban streets. Since, the first step of transportation planning

remains the demand estimation which plays the key-role right from the policy level decisions to ground facility creation; it becomes very important to estimate the demand very carefully and correctly.

Non-motorised modes also known as active transport or human powered transport include walking, cycling, cycle rickshaw, handcarts, etc. Since, virtually every trip begins and ends with a non-motorised mode, whether between a parking lot and an office building or a home and a bus station, whole transport infrastructure network is very much dependent on the efficiency of Non-Motorized Transport (NMT) friendliness. This document provides methodology for evaluating an area with respect to its NMT friendliness and includes guidelines for improvement.

NMT friendliness depends on different parameters listed below:

- How easy or difficult it is to walk on footpath and/or on road?
- How easy or difficult it is to reach public transport stop/station by NMT modes?
- How easy or difficult it is to ride a bicycle on road?

These parameters have been quantified by developing different indices. Value of each index indicates the level of NMT friendliness pertaining to a type of facilities mentioned above. Apart from the NMT friendliness measure, this guideline includes a detailed methodology for identifying the most suitable road crossing infrastructure for given motorized and non-motorized traffic at a location.

The limitations of this guideline document are: i) it does not include goods' movements made by non-motorized modes, ii) it does not consider floating population of the city, if any, iii) it does not include parking facilities at public transport stop/stations for bicycles or any non-motorized para transit mode (e.g. cycle rickshaw).

A broad framework regarding this guidelines document is presented through **Fig. 3.1**.

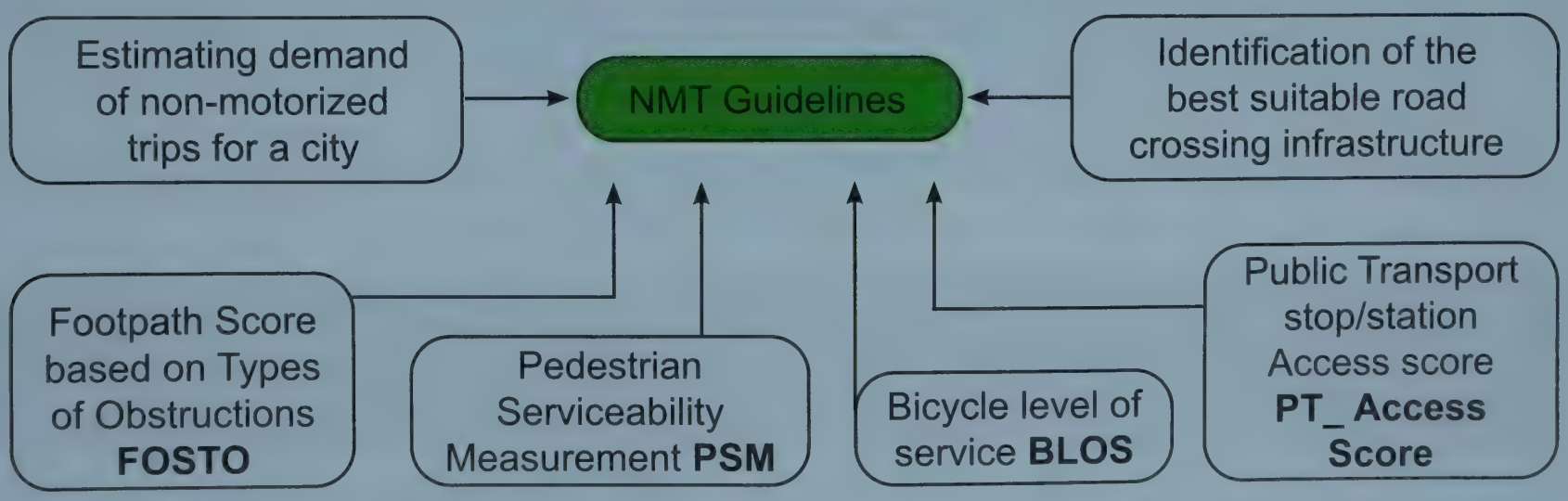

Estimating demand of non-motorized trips for a city
NMT Guidelines
Identification of the best suitable road crossing infrastructure
Footpath Score based on Types of Obstructions **FOSTO**
Pedestrian Serviceability Measurement **PSM**
Bicycle level of service **BLOS**
Public Transport stop/station Access score **PT_ Access Score**

Fig. 3.1 Concept Framework adopted for the Development of NMT Guidelines

3.2 Estimation of Demand for NMT Trips in a City

If a household do not own any vehicle, it can be considered as household dependent on NMT (e.g. walk) and public transport. Similarly, only bicycle owning household usually are from lower income group and therefore they cannot afford to keep a bicycle without any usage. Accordingly,

it has been assumed that if a household owns only bicycle or along with a motorized two wheeler, chances of its usage is high and therefore may be considered for demand estimation. However, if a car owning household owns bicycle too, these households usually are from middle to higher income group and higher chances are that bicycle is not being used for accessibility purpose. Further, among the car owning households, most of households are single car owning households accordingly only one person of household may be using car and remaining all are dependent on walk and public transport. This is applicable for motorized two wheeler owning households as well.

Vehicle ownership information of all the households of a city can be extracted from Census of India for different categories listed in **Table 3.1**. For each category of household listed in **Table 3.1**, average number of trips made by various modes has to be estimated from the household travel data and trip rates available from different sources for a particular city. While planning the facilities for NMT, the estimation of NMT demand needs to be considered. The data shown in **Table 3.2** is for the city of Delhi, however, for a subject city, data from that particular city has to be collected.

Table 3.1 Vehicular Ownership Data from Census of India

S. No.	Vehicular Ownership Data Parameter
1	No vehicle owning Households (NVHH)
2	Bicycle owning Households (BHH)
3	Motorised TW owning Households (TWHH)
4	Car owning Households (CHH)
5	Bicycle + MTW owning Households (B+TWHH)
6	Bicycle + Car owning Households (B+CHH)
7	MTW + Car owning Households (TW+CHH)
8	Bicycle + MTW + Car owning Households (B+TW+CHH)

Table 3.2 Average Number of Non-Motorised Trips made by various Vehicle Owning Households for the City of Delhi

NMT Mode	Number of Trips Produced							
	NVHH	BHH	TWHH	CHH	B+TWHH	B+CHH	TW+CHH	B+TW+CHH
Walk	3.83	3.83	1.53	1.39	1.53	1.39	1.18	1.18
Bicycle	0	1.25	0	0	1.25	1	0	0.22
Cycle Rickshaw	0	0.5	1	1.5	0	1.5	1	1

Based on the input data of **Table 3.1** and the values given in **Table 3.2**, demand of NMT trips can be estimated. Otherwise, a survey can be conducted to arrive at the trip rates for non-motorised modes in a city and the same can be used to arrive at the NMT demand.

3.3 Footpath Score based on Types of Obstructions (FOSTO)

There are many factors that affect pedestrian comfort and also safety on a footpath like obstructions, visibility, safety measures, utility, maintenance, environment etc. However, obstruction plays a crucial role and indirectly influence other factors such as visibility, maintenance, environment issues. In view of this, footpath score which gives indication about the quality in a selected area has been proposed based on the type of obstructions in this document. The footpath score indicates the amount and type of obstructions on footpath and helps in decision making and prioritizing work. To calculate Footpath Score based on Types of Obstructions (FOSTO) score, input parameters are required to be collected from selected site. The parameters include for data collection proportion of road length having footpath (%), proportion of road length having acceptable footpath height (%), proportion of footpath length having Group 1 obstructions (garbage, tree leaves, potholes, personal gardening) (%), proportion of footpath length having Group 2 obstructions (parked vehicles, hawkers) (%) and proportion of footpath length having Group 3 obstructions (constructed urinals, trees, poles) (%). This can be collected with approximation for a rough estimate and can be very detailed for accurate information. **Table 3.3** presents the calculation procedure for FOSTO. In the **Table 3.3**, the parameters along with determined normalised weightages and the sample calculation using the data collected from the field/site are also given. The weightages for these parameters have been estimated from the detailed study carried out in the city of Delhi as part of SUSTRANS study (CRRI, 2017). All the six contributing factors which are identified have been considered for evaluation of footpaths and based on these an index has been developed to assign a score value for different conditions of footpath. This index has been developed using the Analytic Hierarchy Process (AHP), one of the multiple criteria decision-making methods that were originally developed by Saaty (1997). In this method, weightage to these six parameters have been calculated based on the inputs from selected group of experts. Experts have been asked to give their weightage for various parameters relative to other parameters which are being used further for calculating a combined weightage which is called consistency measure in AHP (Advani, *et. al.*, 2017). It can also be observed from the **Table 3.3** that consistency measure value for 'proportion of road length having footpath' and 'average number of ups/downs per 100m length' is maximum compared to other parameters. However, consistency measure value of 0.50 for group 2 obstruction highlights the importance of the issue of parking which is an obstruction to pedestrians. The value of 0.33 for Group 3 obstruction shows that such obstructions are less bothered as compared to other parameters considered. This could be due to the reason that in presence of such obstructions, pedestrians' movement is not comfortable but still walking is possible. Based on the obtained values of consistency measures, an index has been proposed which is called as 'Footpath Score based on Types of Obstructions (FOSTO)'.

Utilizing this data, the score of individual parameters can be calculated by multiplying values observed at the site with weightage value. Final FOSTO score can be calculated from the summation of all individual scores. Here, it is to be noted that the best possible FOSTO score is 100 and score lower than this shows the potential of improvement and score less than 0 highlights the major deficiency in terms of footpath availability and obstructions and negative FOSTO score is inappropriate to use for obtaining any meaningful information.

The calculation of FOSTO also helps in prioritizing the process of improvement along with the quantified impact of it on FOSTO score. Here, it provides FOSTO score of 40.76 for a sample calculation. If obstructions of Group 1 are removed; score can be improved to 53.26. Similarly, possible improvement can be quantified for other types of obstructions removal and facilities provision.

Table 3.3 Calculation of Footpath Score based on Types of Obstructions (FOSTO)

S. No.	Parameter	Normalised Weightage	Observed Values from site (sample calculation)	Score (sample calculation)
1	Proportion of road length having footpath (%)	0.60	60	36.00
2	Proportion of road length having acceptable footpath height (%)	0.40	100	40.00
3	Average number of ups/downs per 100 meter length	(-) 0.57	23	-13.11
4	Proportion of footpath length having Group 1 obstructions (garbage, tree leaves, potholes, personal gardening) (%)	(-) 0.52	24	-12.48
5	Proportion of footpath length having Group 2 obstructions (parked vehicles, hawkers) (%)	(-) 0.50	16	-8.00
6	Proportion of footpath length having Group 3 obstructions (constructed urinals, trees, poles) (%)	(-) 0.33	5	-1.65
	FOSTO Score			40.76

Note: *Calculations are valid for all roads where footpath is mandatory*

3.4 Pedestrian Serviceability Measurement (PSM)

Pedestrian Serviceability Measure (PSM) is to evaluate the serviceability of existing footpaths. This index measures the probable usage of the carriageway in the absence/presence of footpath. Conventional measurement methods are based on pedestrian's speed and/or space available per pedestrian. Both may be misguiding for situations like, i) higher pedestrian speed may be due to the urge of passing the distance in possible shortest time due to odor, etc. and ii) space per pedestrian on footpath may be larger even when footpath is bad, which causes pedestrians to walk on road leaving the footpath space. This document provides a method where level of service measurement includes the space per pedestrian on footpath as well as on road. This method is applicable for all possible scenarios say (i) all pedestrians are walking on footpath, (ii) all pedestrians walking on road in the presence of footpath (iii) all pedestrians are walking on road in the absence of footpath and (iv) pedestrians are walking on footpath as well as on road at the same time. This guideline includes following model for measuring Pedestrian Serviceability Measurement (PSM). The PSM is mathematically represented as given below:

$$\text{PSM Score} = (PPF * S_{PF}) - (PPC * SC_V) \quad (3.1)$$

Where,

PPF = Percentage of pedestrians walking on the footpath

S_{PF} = Space available per pedestrian on footpath

PPC = Percentage of pedestrians walking on carriageway (0 - no pedestrians are walking on the carriageway and 1 – all pedestrians are observed on the carriageway)

SC_V = Score for space occupied by vehicles (on carriageway)

At low vehicle space occupancy, speed of vehicles would be high, which is unsafe for pedestrians. At high vehicle space occupancy, speed of vehicles is less as traffic comes near to stand still position, which becomes uncomfortable for pedestrians to walk on and find their way on the carriageway. At medium vehicle space occupancy, speed of vehicles is moderate and it is not unsafe and uncomfortable for pedestrians to walk on the carriageway, still there are some associated risks. The range of 20-50% is taken as the medium vehicle space occupancy range. As the space occupied by vehicles increases or decreases from this range, it creates discomfort and safety concerns respectively for the pedestrians and therefore those ranges of vehicle space occupancy have been assigned with progressively higher values, which are going to be subtracted from LOS score value and ultimately will show the lower rating for pedestrians' facilities. Based on this concept, 'SC_V' values have been assigned as shown in **Table 3.4**. Different land use types may create different types of obstruction(s) on footpath and causes pedestrians to walk on the carriageway. Accordingly, land use types are not considered directly, however the effect of land use is indirectly considered in evolving Pedestrian Serviceability Measure (PSM).

Table 3.4 Score for Vehicle Space Occupancy (SC_V)

Vehicle Space Occupancy on Carriageway	Score for Vehicle Occupancy (SC_V)
Less than 10%	65
10% - 20%	55
20% - 30%	35
30% - 40%	
40% - 50%	
50% - 60%	55
60% - 70%	65
70% - 80%	65
80% - 90%	65

(Source: CSIR-CRRI, 2017)

3.5 Bicycle Level of Service (BLOS) at Mid-Block

Usually, bicycle lanes do not exist on Indian roads. Wherever it exists it is being used by other motorized vehicles as well. Most commonly, bicycles move along with the motorized vehicles on the same carriageway without any separation. This document provides a model for measuring Bicycle Level of Service (BLOS) for these common situations as given below:

$$\text{BLOS Score} = (-0.1*LD) + (PCU) + (SP) \quad (3.2)$$

Where,

LD = Lateral distance between bicycle and adjacent vehicle -meters

PCU = Passenger car unit PCU value of adjacent vehicle type

SP = proportion of carriageway space occupied by motorized vehicle

Input data required for the above calculation can be extracted from randomly selected snapshots of a video captured on-site covering trap length of 10 meters covering full width of the road. The number of snapshots to be included depends on the variation on-site during survey period. Definitely, larger sample improves the accuracy levels. **Table 3.5** given below can be used to decide the level of service for Bicycles.

Table 3.5 Bicycle Level of Service (BLOS) Ranges

BLOS	Ranges
A	≤ 0.75
B	>0.75 and ≤4.00
C	>4.00

(Source: CSIR-CRRI, 2017)

3.6 Access to Public Transport Stop/Stations (PT Access)

At particular stop/stations, proportion of commuters reaching within 10 minutes by non-motorized modes is the score value for comparing easiness among different transit stop/stations. This has been presented in **Fig. 3.2**.

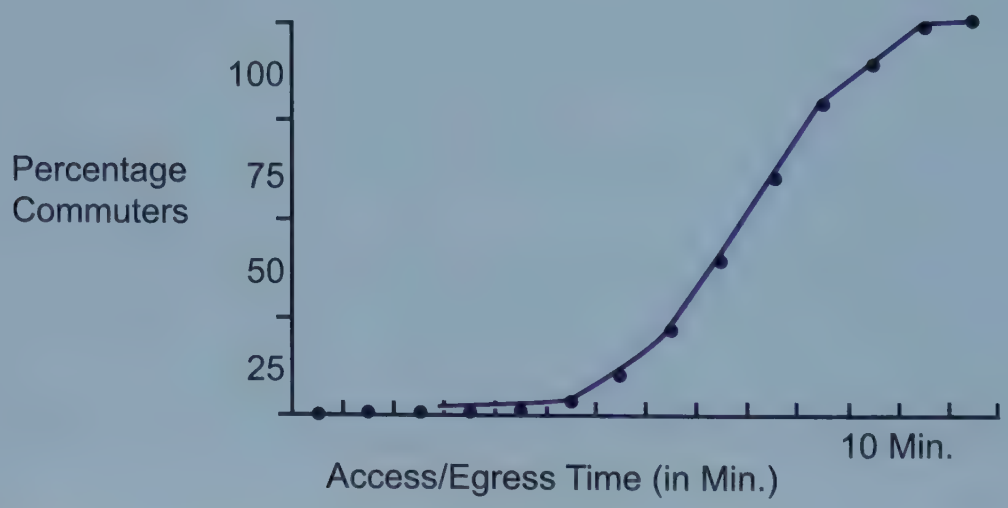


Fig. 3.2 Concept of Calculating Score for Public Transport Stop Access

Similarly, such information for all the transit stop/station collectively represents the score of an area for access to public transport stop/station.

3.7 Infrastructure for Road Crossing by NMT

These guidelines are proposed to identify the most common parameters being considered for making a decision regarding identification of most suitable infrastructure for road crossing by NMT

s given in **Table 3.6**. Delay being the most common parameter, has been considered to make decision regarding most suitable crossing infrastructure. However, delay considered in this uideline reflects the gross delay i.e. delay caused to all road users including pedestrians, non-notorized vehicle users, public transport users, personalized vehicle users and all commercial ehicle users with higher priority on-road for non-motorized and public transport modes leaving east priority for personalized vehicles. First priority for pedestrians is the safe signalised at-rade crossing. Such facilities are suggested for locations where large number of pedestrians re crossing the road as otherwise delay to pedestrians would be too large. Similarly, if huge umber of public transport vehicles are moving at a location, grade-separator may be suggested o minimize delay of public transport commuters. It is suggested that all grade separators must e provided with escalator and lift. The safety measures must be considered effectively for all t-grade crossings. However, grade separator is not correct measure for providing safety to edestrians. Timings for other than peak duration may be analyzed separately. Within the same lay, crossing facility may change accordingly. These are static in nature and location specific nd hence cannot change with time in a day but can change with time in year(s).

Table 3.6 Selection Criteria for the Infrastructure for Road Crossing by NMT

S. No.	Pedestrian Flow (Pedestrians Per Hour - PPH)	Commuter Flow (in 1 hours)	Proportion of NMT & PT Commuters in Total Commuters at Mid-Block		
			Low (less than 30%)	Medium (30 to 60%)	High (more than 60%)
1	High (more than 800 PPH)	Low: less than 17500	At grade signalised	At grade signalised	At grade signalised
		Medium: 17500 to 35000	At grade signalised	At grade signalised	Grade separator
		Heavy: more than 35000	At grade signalised	At grade signalised	Grade separator
2	Medium (between 100 to 800 PPH)	Low: less than 17500	Push button signal OR At grade signalised	Push button signal OR At grade signalised	At grade signalised
		Medium: 17500 to 35000	At grade signalised	At grade signalised	Grade separator
		Heavy: more than 35000	At grade signalised	At grade signalised	Grade separator
3	Low (less than 100 PPH)	Low: less than 17500	Push button signal	Push button signal	Push button signal
		Medium: 17500 to 35000	Push button signal	Grade separator	Grade separator
		Heavy: more than 35000	At grade signalised	Grade separator	Grade separator

(Source: CSIR-CRRI, 2017)

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